Calculations were also performed to evaluate changes in the circumferential stress curves when the radius of the reeled material is significantly increased. The calculations employed the first analytical model with constant core radius of 120mm and wrapping stress of 138MPa. Comparison of these curves (shown in Figures 5B-1 and -2) show that an increased number of layers produced stress curves with deeper minimums. The compressive stress for 460 wraps reached 20MPa (Ex. 1), for 2500 wraps it was 220MPa (Ex. 2), and for 5000 wraps (corresponds to a large roll with radius of 15m) it was 300MPa (Ex. 3). Additional computation with 50,000 wraps (corresponds to a roll with a very large radius of 150m) showed a level of compressive stress of about 600MPa (Figure 5B-2).

These results suggest that during the reeling, the depth of the circumferential stress curve rapidly increases within the first 200 – 300 wraps. After the first 300 wraps, subsequent growth of the circumferential stress curve slows down (see Figures 5B-1 and -2). This indicates that the stress gradient and consequently rapid changes in EFL in the initial layers are higher than that in the outer layers.

From a practical point of view, this implies that very long buffer tubes (on the order of 1000 layers of tube per spool) can not be reeled using constant take-up tension on relatively small spools (core radius about 100mm) without creating high stress gradients. These stress gradients would cause rapid changes in the EFL within the tube in a zone near the spool core that is approximately 1/3 of the total roll thickness. This implies that the roll should be multi-leveled with rigid interlayers to minimize the stress compounding effect. Also, this implies that special attention should be paid to the boundary conditions or physical characteristics at the reel core surface, which includes the stiffness of the reel core and the stiffness of compliant materials or soft pads on the core surface used in the present invention.

In addition, the constant take-up tension should be replaced with a variable take-up tension, as contemplated by the present invention.

The next step taken was to equate the relationship between the stresses experienced by the roll with strains, which directly affect the EFL of a buffer tube. In order to compute the distribution of strains in the roll, equations are needed to relate stresses and strains through material parameters such as Young's modulus and Poisson's ratio. Typically, two major models are used; plane stress or plane strain.

Generally, for elastic orthotropic materials, the relationship between strains and stresses can be presented as follows:

$$\varepsilon_\theta = \frac{\sigma_\theta}{E_\theta} - \frac{\nu_{\theta r}\,\sigma_r}{E_r} - \frac{\nu_{Z\theta}\,\sigma_Z}{E_Z}; \tag{3.14}$$

$$\varepsilon_r = \frac{\sigma_r}{E_r} - \frac{\nu_{r\theta}\,\sigma_\theta}{E_\theta} - \frac{\nu_{zr}\,\sigma_z}{E_Z}; \tag{3.15}$$

$$\varepsilon_z = \frac{\sigma_z}{E_z} - \frac{\nu_{\theta z}\,\sigma_r}{E_\theta} - \frac{\nu_{rz}\,\sigma_r}{E_r}; \tag{3.16}$$

$$\tau_{\theta r} = \frac{\tau_{\theta z}}{G_{\theta z}}; \qquad \tau_{rz} = \frac{\tau_{rz}}{G_{rz}}; \qquad \tau_{zr} = \frac{\tau_{zr}}{G_{zr}}, \tag{3.17}$$

where ε_θ, ε_r, and ε_z are strain components in the circumferential (tangential), radial, and normal to the roll cross section directions, respectively, and $\tau_{r\theta}$, $\tau_{\theta z}$, and τ_{rz} are components of shear strains.

In the plane stress model, component $\sigma_z = 0$ (in the direction perpendicular to the roll cross section or along the axis of winding). When shear strains are negligibly small

compared to the normal strains, the system of Equations 3.14 – 3.17 can be reduced to the following two equations:

$$\varepsilon_\theta = \frac{\sigma_\theta}{E_\theta} - \frac{\nu_{\theta r}\,\sigma_r}{E_r}; \qquad \varepsilon_r = \frac{\sigma_r}{E_r} - \frac{\nu_{r\theta}\,\sigma_\theta}{E_\theta}. \tag{3.18}$$

In the plane strain model, component $\varepsilon_z = 0$ (in the direction perpendicular to the roll cross section or along the axis of winding). For an isotropic material the system of equations for plane strain can be presented in the following form:

$$\begin{Bmatrix} \varepsilon_\theta \\ \varepsilon_r \\ \varepsilon_z \end{Bmatrix} = \begin{bmatrix} \frac{1-\nu^2}{E} & \frac{-\nu(1+\nu)}{E} & 0 \\ \frac{-\nu(1+\nu)}{E} & \frac{1-\nu^2}{E} & 0 \\ 0 & 0 & 0 \end{bmatrix} \begin{Bmatrix} \sigma_\theta \\ \sigma_r \\ \sigma_z \end{Bmatrix}. \tag{3.19}$$

When shear strains are negligibly small compared to the normal strains, the system of Equations 3.19 can be reduced to the following two equations:

$$\varepsilon_\theta = \frac{1-\nu^2}{E}\sigma_\theta - \frac{\nu(1+\nu)}{E}\sigma_r \tag{3.20}$$

$$\varepsilon_r = \frac{1-\nu^2}{E}\sigma_r - \frac{\nu(1+\nu)}{E}\sigma_\theta. \tag{3.21}$$

As can be seen from Equations 3.20 and 3.21, Poisson's ratio plays a role of stress coupling. For low values of Poisson's ratio, $\nu \rightarrow 0$, coupling becomes weak and $\varepsilon_\theta \rightarrow \frac{\sigma_\theta}{E}$ and $\varepsilon_r \rightarrow \frac{\sigma_r}{E}$, which can be the case for buffer tubes.

The computations of strains and EFL in the roll using the first analytical model with the plane stress model was accomplished. In this set of computations, Young's modulus of